



Data-Driven Planning Groups

for Simulation-Based Hospital Bed Capacity Planning

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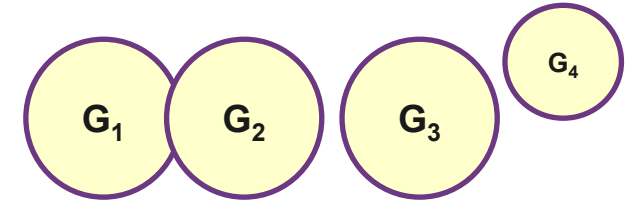
Why Bed Planning Groups?

Bed Planning Groups – Definition & Purpose

- set of patient groups that share a common pool of beds
- have fixed allocated beds and staffing ratios
- designed to increase flexibility in planning, scheduling, exploit resource pooling opportunities

Bed Planning Groups – Then vs. Now

- **In the past:** Specialty-based organization (Medicine, Surgery, Orthopedics, Neurology, etc.)
 - Beds/wards strictly assigned to organizational units
- **Today:** Reduced focus on specialty, increased patient- or planning-oriented focus
 - e.g., insurance class, nursing intensity, age group, etc.



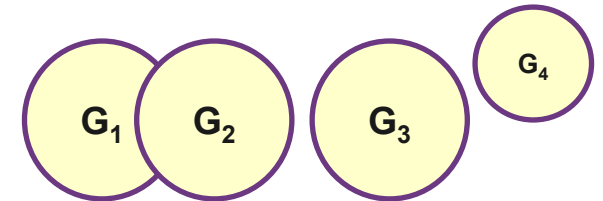
Methodology for Evaluating Planning Groups: Modeling

We propose a new approach for the construction and evaluation of bed planning groups.

Inputs

- Patient case histories including daily bed occupancy over one hospital year.
- Definition of planning groups specifying how annual cases are assigned to groups.
- Overflow policies defining to which group patients are assigned, if their primary group is exhausted.
(→ German: Fremdlieger, translated to: outlier).

FID	Geschlecht	Patientenklasse	Emergency	Datum von	Datum bis	Fachbereich	Station	Patientengrupp	TYPE
1	Weiblich	ALLGEMEIN	NOTFALL	01.01.2026 00:20	01.01.2026 05:21	Ortho / Trauma	Notfallstation	14	Notfallstation
2	Männlich	HALBPRIVAT	NOTFALL	03.01.2026 16:04	-	Allgemeinchirurgie	E3	8	BED
3	Weiblich	ALLGEMEIN	NOTFALL	01.01.2025 17:00	02.01.2025 10:44	Geburtshilfe	Gebs	30	GEBS
4	Weiblich	ALLGEMEIN	NOTFALL	02.01.2025 10:44	04.01.2025 09:46	Geburtshilfe	B0	30	BED
5	Weiblich	ALLGEMEIN	NOTFALL	01.01.2025 04:55	01.01.2025 13:31	Geburtshilfe	Gebs	30	GEBS
6	Weiblich	ALLGEMEIN	NOTFALL	01.01.2025 13:31	03.01.2025 08:39	Geburtshilfe	B0	30	BED



Target Planning Group	Overflow Planning Groups		
	Prio 1	Prio 2	Prio 3
G1	G2	G3	G4
G2	G1	G3, G4	
G3	G1, G2	G4	
G4	G1	G2	G3

Objective

- How can total bed capacity be optimally distributed across planning groups in order to minimize the number of **outlier days**?

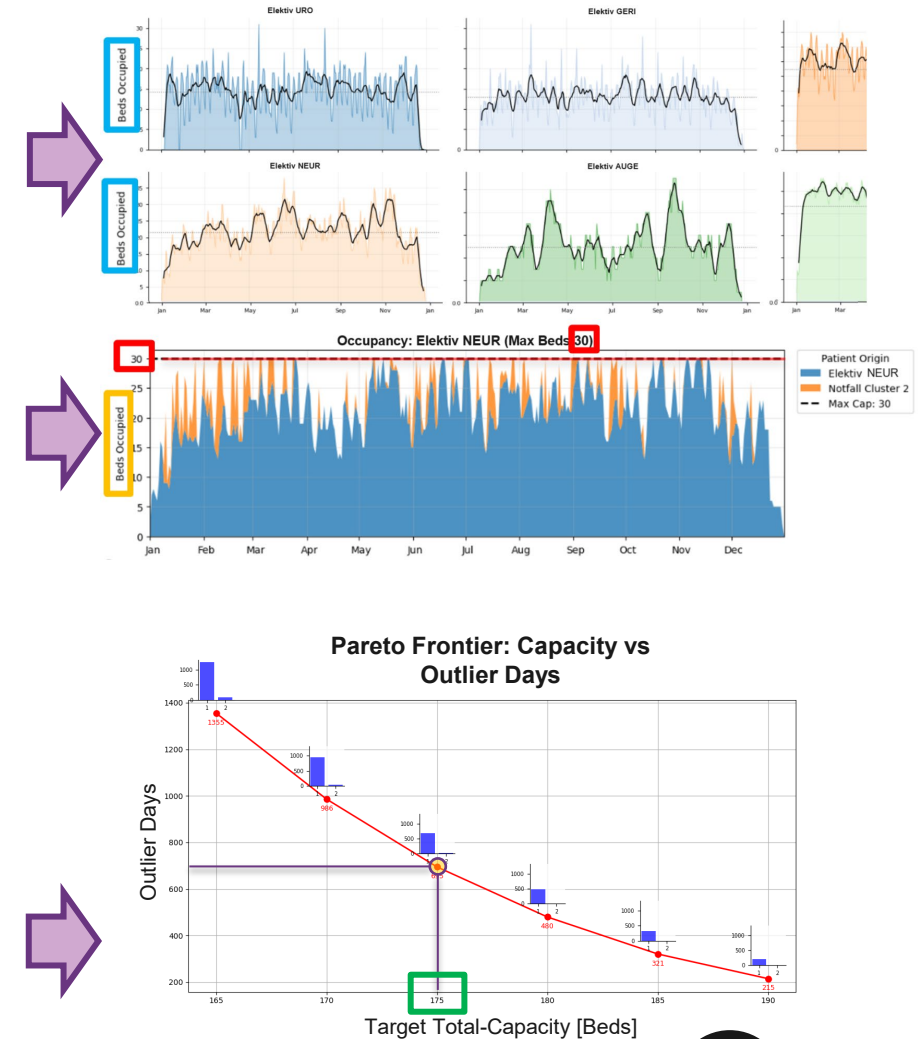
Methodology for Evaluating Planning Groups: Modeling

Solution Approach: MILP with Google OR-Tools CP-SAT

- Parameters: B_{it} = bed demand of group i on day t ,
 C_{max} = Granted Total Capacity [Beds]
- Decision Variables:
 - x_{ijt} = number of patients from group i , laying in group j on day t (if $i = j$, home group).
 - y_i = bed capacity assigned to planning group i .
- Objective Function: Minimize weighted sum of outlier days, based on predefined priority weights.

Pareto Analysis: Trade-off between

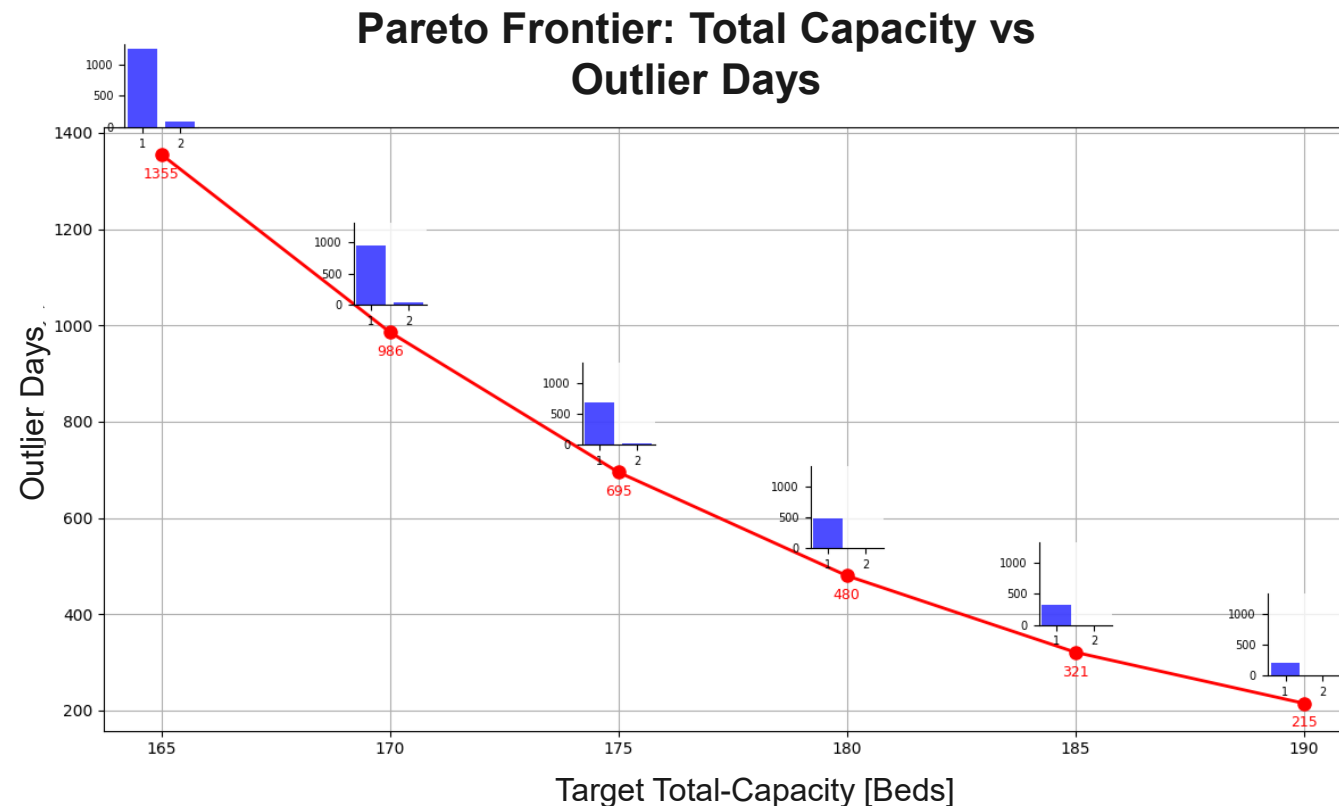
- X-axis: Total available hospital bed capacity
- Y-axis: Cumulative outlier days



Methodology for Evaluating Planning Groups: Results

- Trade-Off Visualization

The following analysis shows the baseline Pareto frontier, including a visualization of the distribution of outlier days by priority level (Priority 1 / 2) for selected solutions.



Methodology for Evaluating Planning Groups: Weaknesses

- **Aggressive back-transfer policy:** The model implies an aggressive back-transfer policy. As soon as a outlier patient can be transferred from a priority-2 to a priority-1 ward, this is done.
- **No support for operational decisions:** The model does not account for **operational decisions such as temporarily closing wards** when no patients are present (e.g., on weekends).
- **Excessive total bed requirement:** The sum of the maxima of all groups is always at least as large as the overall maximum, but often significantly higher because peaks in different groups occur on different days.
- **Low average utilization:** If an extreme day with particularly many patients occurred over the year, this single peak will determine capacity. On all other days, beds are then free – utilization decreases.

Robustness of results

How robust is our MILP model against random variations of patient history cases?

We hope that the shape of the Pareto Frontier (and the distribution of total capacity over the planning groups) does not change significantly, when we repeat the optimization with patient history data from a different, but statistically similar, year ...

Experiments performed

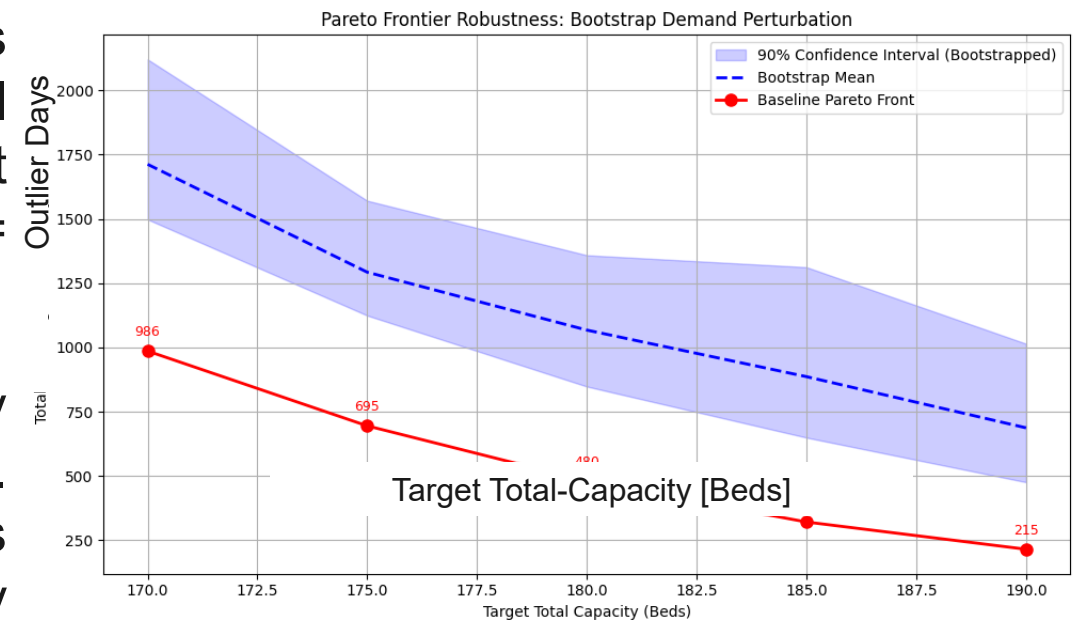
- Test the model with **bootstrapped data sets**
- Test the model with **small perturbations in key parameters** (e.g., LoS variation)
- Test the model with the application of a **moving average window** to the occupancy data

Robustness of results

Bootstrapping on Patient history cases

- **Approach:** Generate N case histories using bootstrapping (sampling with replacement from original data set of size N).
- **(Unexpected) Result:** Pareto Frontier moves upwards. Reason: Resampling creates local «patient congestion» (clumping). [N different arrival times in original data, give only $1 - e^{-1} = 63\%$ different arrival times in bootstrap sample]
- This problem could be avoided by randomly distributing the sampled dates over the entire year. This would smooth random peaks, but destroys (operational) seasonality (e.g. low occupancy around Christmas and Summer holidays)

Pareto Frontier Robustness: Bootstrap Demand Perturbation

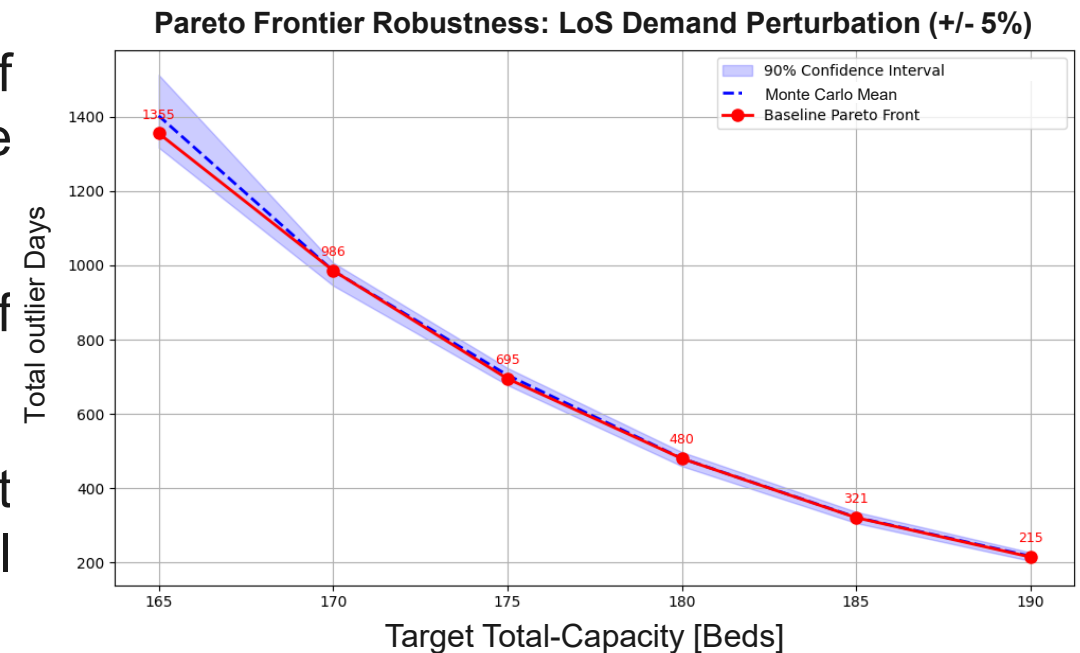


Robustness of results

Perturbation Length of Stay data

Idea: Test the **robustness of planning group capacities against real process fluctuations** (e.g. discharge delays).

- **Approach:** Variation of the length of stay (LoS) of each patient by a normally distributed factor (we used +/- 5% deviation).
- **Result:** Pareto Frontier seem pretty stable, even if total capacity is hardly enough to match demand.
- **Remark:** Admission start dates and «patient composition» remain unchanged (no artificial clumping, preservation of seasonality).



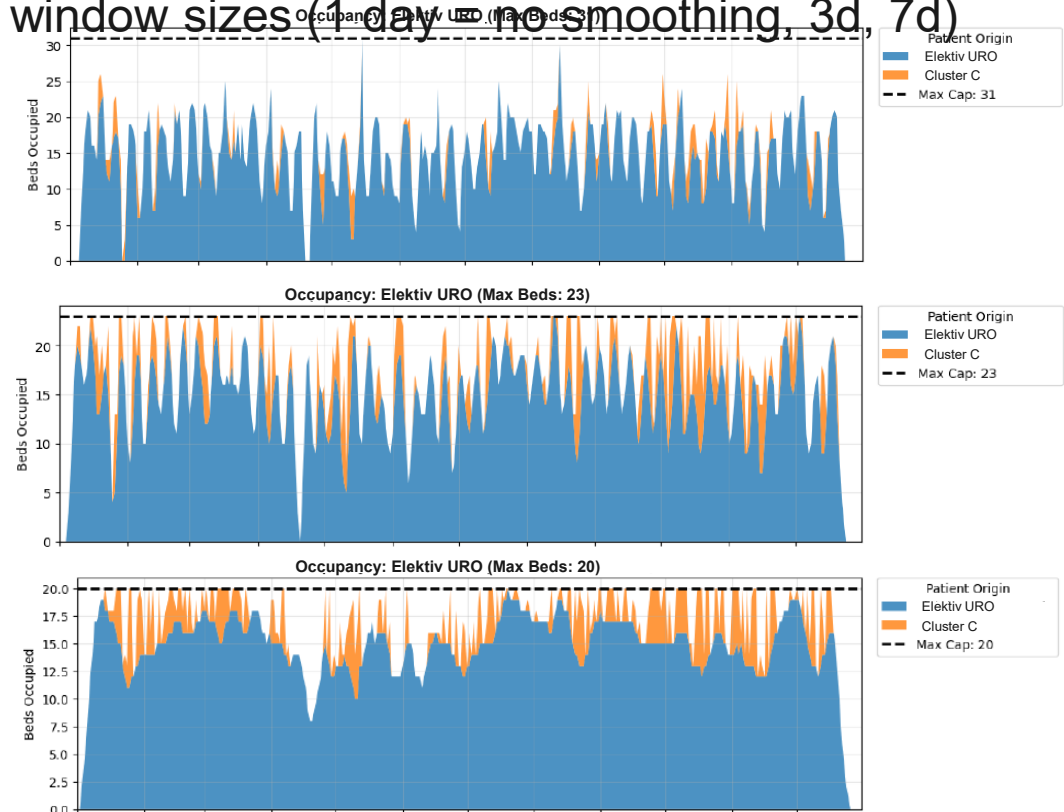
Robustness of results

Application of a moving average window to the occupancy data

Idea: Exact location of peaks on time axis is quite random. Moreover, hospitals anticipate and react on peaks.

- **Approach:** Replace original data with moving average data ...
- **(Preliminary) Results:** Pareto Frontier moves downwards. At first sight, hospital judges the new Pareto Frontier as more realistic

Figures shows the occupancy time series of one planning group using different moving average window sizes (1 day - no smoothing, 3d, 7d)



Questions

Domain - specific Questions

- Back-transfer policy: «Priority 2 bed → Priority 1 bed», is this done in practice? Practice requires back-transfer within 24/48/72 h. Introduce a penalty for long outliers?
- Focus on number of transfers instead of outlier bed days?
- Is the approach transferable to OR planning groups?
- Should additional aspects & constraints (rooms, wards, staff availability, ...) be considered?
- Are there experiences with integration of OR- and bed-planning groups?
- Challenges in practice (wards, staff/skill-mix, ...)?
- What soft criteria determine if 2 patient groups can be put together in the same planning group?

- Is the definition of planning groups a task for algorithms or a task for human experts (doctors)?
- How could quantitative methods provide decision support when definition planning groups?

Methodological Questions

- Retrospective data have the bias that they always fit. Simulation + this methodology have no “cap”. Significance / problems?
- How should stochastic/systematic changes in demand be handled?

Thank you very much for your attention!

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